Climate change and small pelagic fish price volatility

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Abstract

Price volatility, an indicative measure of price uncertainty, is an important factor influencing fisheries cost, income, food security, and pressure on fish stocks. An increase in price volatility means that prices are varying more, making it more difficult to adjust the activities accordingly. This paper explores price volatility changes for the small pelagic fish—a key group for food security—related to the potential outcomes of climate change, such as tropical widening. With the tropicalization of temperate and polar marine ecosystems due to species composition changes, one would expect that overall price volatility for the small pelagics may be reduced over time because volatility in the tropical region is on average the lowest. However, we find an empirical evidence that price volatility for small pelagic species has increased relatively in the tropical and sub-polar regions beyond what can be explained by changes in landing levels and the variation in the landings.

Keywords Small pelagics · Price volatility · Fisheries

1 Introduction

Climate change affects marine fisheries directly and indirectly. Direct outcomes include changes in marine species range, timing of reproduction, eggs and larvae dispersion, abundance, and individual maximum size (Hollowed et al. 2013; Laffoley and Baxter 2016). Indirect consequences include uncertainty in the landings (Brander 2015) as well as in the price received for the landed fish (Dahl and Oglend 2014), and income impacts on fishers' livelihoods and coastal communities (Asche et al. 2018; Selig et al. 2019). Price volatility, as a

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measure of price uncertainty, is a key factor informing about fisheries income, food security, and pressure on pelagic fish stocks. Furthermore, prices can be informative measures of changes in ecological conditions even in settings where it is difficult to tease out these relationships from quantity data due to contaminated control variables (Smith et al. 2017). The importance of fisheries production for livelihoods has led to a number of studies investigating the economic consequences of climate change (Allison et al. 2009; Sumaila et al. 2011; Porter et al. 2014; Lam et al. 2016; Blasiak et al. 2017), but so far, little attention has been given to information that can be obtained from price volatility. Here, we investigate whether price volatility has increased in three regions for catches of small pelagic fish—an important resource for food and feed. Comparing volatility between two periods (before and after 1979), an increase in price volatility is found for the tropical region as well as the sub-polar region (Fig. 1). Moreover, the variation in landings influences price volatility more than average landing levels. Consequently, a higher degree of economic uncertainty for small pelagic fisheries may be expected in the future with larger stock and catch variation given the projected increase in the intensity and frequency of extreme events influencing fish stocks due to climate change.

Small pelagics, such as sardines, herrings, and anchovies, are short-lived fish highly dependent on oceanographic conditions (Lehodey et al. 2006; Cochrane et al. 2009; Merino et al. 2010). As such, they are vulnerable to impacts of potential changes in fisheries pattern due to climate change. The group is important to both fisheries and aquaculture activities— small pelagics comprise 30% of global landings, and a significant share is reduced to fish oil and meal used in aquafeeds (Deutsch et al. 2007; Tacon and Metian 2008, 2015; FAO 2019). Moreover, in recent years, fish oil has also become popular as a human nutritional supplement (Misund et al. 2017). Therefore, they are a key seafood group for food security (Allison et al. 2009; Smith et al. 2010).

Among the several possible outcomes from climate change, expansion or contraction of the marine species spatial distribution is of particular interest (Allison et al. 2009; Sumaila et al. 2011; Fossheim et al. 2015; Rutterford et al. 2015; Fenichel et al. 2016; Pecl et al. 2017). In fact, Staten et al. (2018) suggest a poleward expansion of the tropics in recent decades, i.e., a tropical widening. Moreover, predictions that the temperature increase in the polar and sub-polar regions will exceed the global average increase (Barange et al. 2006) suggest not only an intensive local species reduction, in worst cases extinction in the sub-polar regions, tropics, and semi-enclosed seas, but also high species invasion intensity in the polar region (Cheung
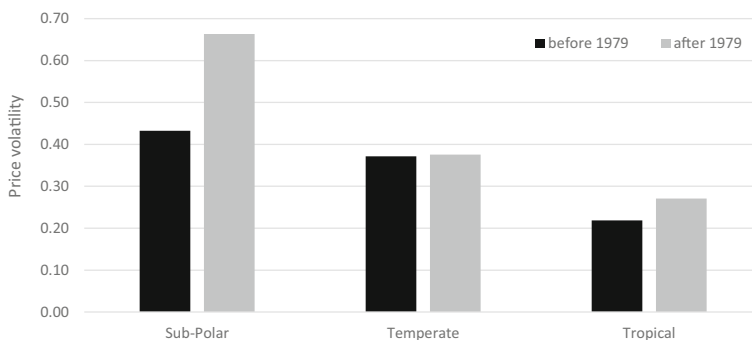
Fig. 1 Small pelagics' price volatility before and after 1979 by climate region. Price volatility is the standard deviation of price log-returns

et al. 2009). This may be seen as a tropicalization of temperate marine ecosystems due to species composition changes (Laffoley and Baxter 2016). If this occurs, one would expect that overall price volatility may be reduced over time, because volatility in the tropical region is on average the lowest (Fig. 1).

However, extreme events are predicted to become more frequent and intense, including the El Niño phenomena (Easterling 2000; Hansen et al. 2012; Cai et al. 2014; Laffoley and Baxter 2016). This will contribute to more variation in fish stocks and landings. This feature indicates that climate change may cause higher stock, landings, and price volatility over time as the geographical range shifts. In fact, several studies note the importance of looking at variability in addition to changes in mean levels to obtain a more complete picture of the effects of climate change (Katz and Brown 1992; Brander 2007; Wernberg et al. 2013). Evidence of accelerated global warming in the last two decades with respect to the relatively stable prior period (Hansen et al. 2012) and evidence of tropical widening from 1979 (Staten et al. 2018) provide an opportunity to investigate the relative strength of the price volatility hypotheses for the three climate regions, namely, sub-polar, temperate, and tropical dummies, before and after 1979.

2 Methods

Price volatility describes the degree of variation in prices, which is a result of the underlying characteristics of its production and market. For fisheries, and in particular small pelagic fish, production depends in large on the environmental conditions, and price volatility will mainly be a function of the amount of fish caught and its variation. Moreover, Tveterås et al. (2012) indicates a highly integrated market for pelagic fisheries (Tveterås et al. 2012). This means that the market substitution among the pelagic fish and other products (e.g., fishmeal and soybean meal—see Asche and Tveterås 2004) limits the market effect on price volatility. Thus, the hypothesis testing in this paper will account for the main variables influencing supply, i.e., amount of fish caught and its variation. As there is a global market, no attempt will be made to distinguish between regional markets.

Data on small pelagic fish (< 30 cm), ex-vessels' value (US$), and quantity (kg) from large marine ecosystem (LME) (Pauly and Zeller 2015) was used to estimate yearly prices (value divided by quantities) from 1950 to 2006. Large marine ecosystems are areas defined by its ecological and oceanographic characteristics rather than just political or economic criteria (Sherman and Hempel 2009). Each large marine ecosystem was classified by climate region: tropical, temperate, and sub-polar regions (Table 1). Table 2 gives the average volatility, the mean of standard deviations of log-returns for each series in the group. Moreover, Table 2 shows a descriptive analysis of the data set by climate regions, including the number of series available, the number of full-sample series available, and the mean quantity caught by fisheries and its coefficient of variation. For six LMEs, the data for small pelagic (< 30 cm) was not available online or the time series have missing data.[1]

Thus, the effect of variables that vary across the three groups, such as the harvested quantity and the coefficient of variation of the harvested quantity (the standard deviation divided by the

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[1] Gulf of California LME, New Zealand Shelf LME, and Iceland Shelf LME have 8, 3, and 1 missing observations, respectively. While East Central Australian Shelf LME, Canadian High Arctic - North Greenland LME, and Laptev to Chukchi Sea LME did not present data on the small pelagic fish.

Table 1 Large marine ecosystems classified by climate region and its price volatility 1950–2006

Region	LME	Price volatility*
Sub-polar	Chukchi Sea	0.85
Sub-polar	Beaufort Sea	0.14
Sub-polar	West Greenland Shelf	0.32
Sub-polar	East Greenland Shelf	0.97
Sub-polar	Barents Sea	1.09
Temperate	East Bering Sea	0.31
Temperate	Gulf of Alaska	0.15
Temperate	Hudson Bay	0.35
Temperate	Newfoundland-Labrador Shelf	0.55
Temperate	Scotian Shelf	0.39
Temperate	California Current	0.42
Temperate	Northeast US continental Shelf	0.45
Temperate	Iceland Shelf	1.41
Temperate	Norwegian Sea	0.70
Temperate	Baltic Sea	0.42
Temperate	North Sea	0.32
Temperate	Faroe Plateau	0.54
Temperate	Celtic-Biscay Shelf	0.36
Temperate	Iberian Coastal	0.39
Temperate	Mediterranean Sea	0.34
Temperate	Black Sea	0.43
Temperate	West Bering Sea	0.73
Temperate	Sea of Okhotsk	0.16
Temperate	Oyashio Current	0.14
Temperate	Sea of Japan/East Sea	0.18
Temperate	Yellow Sea	0.30
Temperate	East China Sea	0.20
Temperate	Kuroshio Current	0.18
Temperate	Humboldt Current	0.29
Temperate	Patagonian Shelf	0.34
Temperate	Southwest Australian Shelf	0.24
Temperate	Southeast Australian Shelf	0.25
Temperate	New Zealand Shelf	0.41
Tropical	Pacific Central-American Coastal	0.29
Tropical	Gulf of Mexico	0.10
Tropical	Caribbean Sea	0.09
Tropical	South Brazil	0.29
Tropical	East Brazil Shelf	0.44
Tropical	South Brazil Shelf	0.26
Tropical	Canary Current	0.26
Tropical	Guinea Current	0.48
Tropical	Benguela Current	0.53
Tropical	Agulhas Current	0.12
Tropical	Somali Coastal Current	0.26
Tropical	Red Sea	0.32
Tropical	Arabian Sea	0.31
Tropical	Bay of Bengal	0.15
Tropical	Gulf of Thailand	0.38
Tropical	South China Sea	0.25
Tropical	Sulu-Celebes Sea	0.32
Tropical	Indonesian Sea	0.28
Tropical	West-Central Australian Shelf	0.21
Tropical	Northwest Australian Shelf	0.18
Tropical	North Australian Shelf	0.23
Tropical	Northeast Australian Shelf-Great Barrier Reef	0.26
Tropical	Gulf of California	0.53

*Price volatility is the standard deviation of the log-return of prices

mean of the harvested quantity) was tested using regression analysis. The large marine ecosystem time series having no more than 8 missing observations were used in this analysis (see Table 2). The log-linear regression to be estimated is given as:

$$\ln\text{volatility}_i = \mu + \sum_{j=1}^{p}\beta_j D_{i,j} + \sum_{k=1}^{l}\alpha_k \ln\left(X_{i,k}\right) + \varepsilon_i,$$

where volatility$_i$ is the standard deviations of log-returns for each LME time series i, and $D_{i,j}$ is a dummy variable taking a unit value if the LME$_i$ belongs to group j before and after 1979 (models using 1979 and 1980 as the start of the second period were tested and provided similar results). Considering n is the number of LMEs in each group j, then $p = n - 1$ and μ is the volatility of the remaining reference group.

The vector $X_{i,k}$ contains additional explanatory variables. These are the harvested quantity in the LME$_j$ and the coefficient of variation of the harvest. The null hypothesis—no differences in volatility between the LME climate region groups (sub-polar, temperate, and tropical) before and after 1979—was tested using the Wald test.

3 Results and discussion

Before 1979, price volatility in the tropical region was significantly lower than the other two regions, while there was no statistical difference between the temperate and the sub-polar region (Table 3). Price volatility remains at the same level with no statistical difference in the temperate region in both periods, but it increases in the two other regions. The tropical region's price volatility increases so much that it is not statistically different from the temperate region after 1979. The price volatility in the sub-polar region increases so that it is significantly higher than the price volatility in the tropical and temperate regions after 1979. Hence, price volatility has increased in two of the three regions. The fact that the price volatility in the temperate region does not change also implies that the significant shift in the use of many small pelagics towards feed for the rapidly growing aquaculture industry for fishmeal (Tacon and Metian 2008, 2015) and also for human nutritional supplements (Misund et al. 2017) has not fundamentally changed the price volatility for the small pelagics.

Other potential factors influencing price volatility are harvest levels and its coefficient of variation. Harvest level influences volatility positively although with a very small numerical effect. This is somewhat surprising, as usually higher volumes in a market is expected to reduce price volatility, as indicated in Oglend and Sikveland (2008) and Marvasti and Lamberte (2016). However, the particular production process for small pelagics, which is largely due to natural variation rather than more producers as in a traditional industry that

Table 2 Descriptive analysis and volatility by climate region

Climate regions	Volatility*	St. Dev	# series	# series—full sample	Mean quantity (t × 1000)	Mean CV quantity
All	0.15	0.07	59	53	271,434	0.80
Sub-Polar	0.57	0.24	8	5	91,035	2.13
Temperate	0.39	0.18	28	26	315,493	3.48
Tropical	0.26	0.10	23	22	222,814	1.33

*Volatility is the standard deviation of the log-return of prices

Table 3 Differences in volatility across the climate regions before and after 1979 with temperate region before 1979 as the base. As the continuous variables are in natural logarithms, the estimated parameters indicate the percentage increase in price volatility due to a 1% increase in the relevant variable. The price volatility in log was regressed by the three climate regions, namely, sub-polar, temperate, and tropical dummies, before and after 1979; the log of the average of harvested quantity; and its coefficient of variation (CV)

Independent variables	Coef.	Robust Std. Err.
Constant	− 1.261	0.206***
Log harvest quantity	0.031	0.016*
Log CV quantity	0.278	0.057***
Temperate region after 1979 dummy	− 0.013	0.113
Tropical region before 1979 dummy	− 0.597	0.142***
Tropical region after 1979 dummy	− 0.149	0.117
Sub-polar region before 1979 dummy	0.206	0.141
Sub-polar region after 1979 dummy	0.489	0.236**
R^2	0.375	
F value (7, 98)	9.02***	

*Significant at a 10% level;

**Significant at a 5% level

***Significant at a 1% level

spreads risks, goes a long way to explain this result. Dahl and Oglend (2014) show that small pelagics is the seafood species group with the highest price volatility, and its price volatility is higher than all other foods, underscoring this unpredictability. The strong impact of the variation in landings as measured by the CV variable further highlights the importance of looking at variation in itself. Variation in the quantity landed is much more important than how much is landed for price volatility.

The consequences of higher economic uncertainty for fisheries reflected by higher price volatility are different from consequences of higher average (Porter et al. 2014). An increase in price volatility means that prices are varying more, making it more difficult to adjust activities accordingly. This is critical for activities such as fisheries, where fishers have limited flexibility due to a given number of vessels. Moreover, higher price volatility means higher risks and costs associated with the activities, and less stable revenue for fisheries and aquaculture industries. Given most fishers as risk averse (Eggert and Martinsson 2004; Smith and Wilen 2005), they will have less incentive to invest in the activity.

Other factors that influence price volatility are governance and the degree of market integration. Efficient fisheries management provides more individual control over catches and contributes not only to a more predictable revenue (Holland et al. 2017) but also to healthier fish stocks and improved quality of the fish. Although several small pelagic stocks are considered overexploited, fisheries management has improved in the last decades. More fisheries, including the Peruvian anchoveta, have been managed by catch share systems, which tend to be more efficient than open-access systems (Costello et al. 2008; Jardine and Sanchirico 2012; Birkenbach et al. 2017). However, our results indicate that while improvements in management may contribute to reduce harvest and price volatility, this has not been sufficient to counter the effects of stronger natural variability.

In addition, the degree of substitution of the small pelagics, among the different species and in relation to other alternatives for its different uses, i.e., integration among the markets, sets the limits of price variation due to changes in their supply (Asche and Tveterås 2004; Barange et al. 2006; Tveterås and Tveterås 2010; Misund et al. 2017). For instance, fishmeal, made

mostly from small pelagics, has been a substitute in feed by soybean meal. As shown in Asche and Tveterås (2004) and Asche et al. (2013), both prices are highly integrated, which limits the market effect on price volatility.

The results in this paper show that price volatility for small pelagic species has increased in the tropical and sub-polar regions beyond what can be explained by changes in landing levels and the variation in landings. Hence, natural variation associated with climate change is impacting pelagic stocks. Given the important role of the small pelagics group in ecosystems as well as for livelihoods, a higher degree of uncertainty associated with small pelagics prices compounded by the uncertainty of the stock availability for fisheries is a challenge for decision-makers when considering the implications of climate change. This is particularly challenging in many poorer countries that are disproportionally dependent on small pelagic as a source for nutrients and protein (Allison et al. 2009; Hicks et al. 2019).

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

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